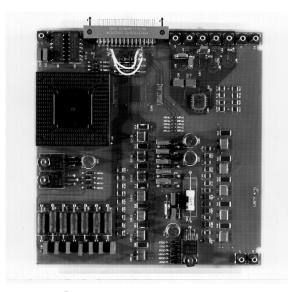
Printed Wiring Board Surface Finishes



Cleaner
Technologies
Substitutes
Assessment

VOLUME 1

Jack R. Geibig, Senior Research Associate Mary B. Swanson, Research Scientist and the PWB Engineering Support Team



This document was produced by the University of Tennessee Center for Clean Products and Clean Technologies under grant #X825373 from EPA's Design for the Environment Branch, Economics, Exposure, & Technology Division, Office of Pollution Prevention and Toxics.



PWB Engineering Support Team

The PWB Engineering Support Team consisted of University of Tennessee faculty and graduate students who developed analytical models for the project and/or authored sections of this document. Members of the Team and the sections to which they contributed are listed below:

Exposure Assessment and Risk Characterization

Dr. Chris D. Cox, Associate Professor of Civil and Environmental Engineering, Dr. R. Bruce Robinson, Professor of Civil and Environmental Engineering, and graduate research assistants in Civil and Environmental Engineering: Aaron Damrill, Jennie Ducker, Purshotam Juriasingani, and Jeng-hon Su.

Cost Analysis

Dr. Rupy Sawhney, Assistant Professor of Industrial Engineering and Director, Lean Production Laboratory, and graduate research assistants in Industrial Engineering: Aamer Ammer.

Disclaimer

This document was written by the grantee. It has not been through a formal external peer review process. Some information in this document was provided by individual technology vendors and has not been independently corroborated by EPA or the University of Tennessee. The use of specific trade names or the identification of specific products or processes in this document are not intended to represent an endorsement by EPA or the U.S. Government. Discussion of federal environmental statutes is intended for information purposes only; this is not an official guidance document, and should not be relied on by companies in the printed wiring board industry to determine applicable regulatory requirements.

For More Information

To learn more about the Design for the Environment (DfE) Printed Wiring Board Project or the DfE Program, please visit the DfE Program web site at:

www.epa.gov/dfe

The DfE web site also contains the document, *Cleaner Technologies Substitutes Assessment: A Methodology and Resources Guide*, which describes the basic methodology used in this assessment.

To obtain copies of DfE Printed Wiring Board Project technical reports, pollution prevention case studies, and project summaries, please contact:

Pollution Prevention Information Clearinghouse (PPIC)
U.S. Environmental Protection Agency
1200 Pennsylvania Ave., N.W. (7407)
Washington, DC 20460
Phone: (202) 260-1023

Fax: (202) 260-4659 E-mail: ppic@epa.gov

Web site: www.epa.gov/opptintr/library/ppicdist.htm

To learn more about the University of Tennessee Center for Clean Products and Clean Technologies, visit the Center's web site at:

eerc.ra.utk.edu/clean/

Acknowledgments

This Cleaner Technologies Substitutes Assessment (CTSA) was prepared under a grant from the U.S. Environmental Protection Agency's Design for the Environment (DfE) Program, Office of Pollution Prevention and Toxics, by the University of Tennessee (UT) Knoxville Center for Clean Products and Clean Technologies and the PWB Engineering Support Team, with assistance from numerous UT students and staff. The authors would like to acknowledge the outstanding contributions of **Lori Kincaid**, UT Center for Clean Projects and Clean Technologies, who provided guidance throughout the project; **Catherine Wilt**, UT Center for Clean Projects and Clean Technologies, who researched and wrote the Regulatory status section of this document; **James Dee**, UT Center for Clean Projects and Clean Technologies, who assisted with the development of the Human Health and Ecological Hazards Summary; and **Margaret Goergen**, who was the document production manager.

This document was produced as part of the DfE Printed Wiring Board Project, under the direction of the project's Core Group members, including: **Kathy Hart**, Project Lead and Core Group Co-Chair, U.S. EPA, Office of Pollution Prevention and Toxics (OPPT), Economics, Exposure and Technology Division (EETD), DfE Branch; **Holly Evans**, formerly of IPC—Association Connecting Electronics Industries (IPC), and **Fern Abrams**, IPC, Core Group Co-Chairs; **Dipti Singh**, Technical Lead and Technical Workgroup Co-Chair, U.S. EPA, OPPT, EETD, DfE Branch; **John Sharp**, Teradyne Inc., Technical Workgroup Co-Chair; **Michael Kerr**, BHE Environmental, Inc., **John Lott**, DuPont Electronics; **Greg Pitts**, Ecolibrium; **Gary Roper**, Substrate Technologies, Inc.; and **Ted Smith**, Silicon Valley Toxics Coalition. Many thanks also to the industry representatives and other interested parties who participated in the project's Technical Workgroup, especially **David Ormerod** of Dexter Electronic Materials (now Polyclad Technologies - Enthone), **Michael Schectman** of Technic, Inc., **David Hillman** of Rockwell International Corp., and **Eric Brooman** of Concurrent Technologies Corporation.

We would like to acknowledge **Ron Iman** of Southwest Technology Consultants for his work in analyzing and presenting the results of the performance demonstration, and **Terry Munson** of Contamination Studies Laboratory (CSL), Inc., for conducting a failure analysis and helping to present the performance demonstration results. We also appreciate the efforts of **Jeff Koon** of Raytheon Systems Company and **David Hillman** for their help in planning and conducting the performance demonstration. Recognition is also given to **ADI/Isola**, who supplied the materials to build the performance demonstration test boards, to **Network Circuits** for volunteering to build the boards, and to the test facilities that ran the boards through their surface finish lines and provided critical data for the study. Performance demonstration contractor support was provided by Abt Associates, Inc., of Cambridge, MA, under the direction of **Cheryl Keenan**.

EPA Design for the Environment Workgroup

We would like to express appreciation to the U.S. EPA Office of Pollution Prevention and Toxics Design for the Environment Workgroup, who provided valuable expertise in the development of this CTSA and reviewed all draft documents.

Andrea Blaschka
Susan Dillman
Conrad Flessner
Franklyn Hall
Find Lehman
Fred Metz
Dave Monroe
Jerry Smrchek

Susan Krueger

Participating Suppliers

We would like to thank the suppliers for their participation in the DfE Printed Wiring Board Surface Finishes Project. In addition to supplying critical information regarding the various technologies, these companies also made significant contributions in planning and conducting the performance demonstration.

Alpha Metals

(now Polyclad Technologies-Enthone) Steve Beigle 50 Burr Ridge Parkway Burr Ridge, IL 60521 (630) 794-9329

Dexter Electronic Materials

(now Polyclad Technologies-Enthone) David Ormerod 144 Harvey Road Londonderry, NH 03053 (603) 645-0021, ext. 203

Electrochemicals, Inc.

Paul Galatis 5630 Pioneer Creek Maple Plain, MN 55359 (612) 479-2008

Florida CirTech

Mike Scimeca 1309 North 17th Avenue Greeley, CO 80631 (970) 346-8002

MacDermid, Inc.

Don Cullen 245 Freight Street P.O. Box 671 Waterbury, CT 06702 (203) 575-5658

Technic, Inc.

Michael Schectman 1 Spectacle Street Cranston, RI 02910 (401) 781-6100

Performance Demonstration Sites

We would like to recognize the companies and their facilities that participated in our performance demonstration, for donating the time and materials necessary to carry out the testing. We also appreciate the assistance they provided in gathering data necessary to conduct this assessment.

AIK Electronics (UK) Ltd. (formerly General

Philips Printed Circuits) Technology Corp.)

Artetch Circuits Ltd. H-R Industries

Central Circuits Inc. Parlex Corp.

Circuit Connect Inc. Quality Circuits Inc.

Circuit Wise Inc. Sanmina Corp. (formerly Altron Inc.)

Diversified Systems Sanmina Corp. (formerly Hadco Corp.)

Solder Station One, Inc.

Table of Contents

Execu	utive Su	mmary ES-1
Chap	ter 1	
_		
1.1		t Background
	1.1.1	EPA DfE Program 1-2
	1.1.2	DfE PWB Program 1-2
1.2	Overv	iew of PWB Industry
	1.2.1	Types of Printed Wiring Boards
	1.2.2	Industry Profile
	1.2.3	Overview of Rigid Multi-Layer PWB Manufacturing
1.3	CTSA	Methodology
	1.3.1	Identification of Alternatives and Selection of Project Baseline 1-8
	1.3.2	Boundaries of the Evaluation
	1.3.3	Issues Evaluated
	1.3.4	Primary Data Sources 1-11
	1.3.5	Project Limitations
1.4	Organ	ization of this Report
Refer	ences	1-16
Chap	ter 2	
Profil	e of the	Surface Finishing Use Cluster
2.1	Chem	istry and Process Description of Surface Finishing Technologies 2-1
	2.1.1	Process Sequence of Surface Finishing Technologies 2-1
	2.1.2	Overview of the Surface Finishing Manufacturing Process
	2.1.3	Chemistry and Process Descriptions of Surface Finishing Technologies 2-4
	2.1.4	Chemical Characterization of Surface Finishing Technologies 2-17
2.2	Additi	onal Surface Finishing Technologies
	2.2.1	Immersion Palladium
Refer	ences	2-25
~		
Chap		
		ag and Comparison
3.1		e Release Assessment
	3.1.1	Data Sources and Assumptions
	3.1.2	Overall Material Balance for Surface Finishing Technologies
	3.1.3	Source and Release Information for Specific Surface Finishing
	0.1.1	Technologies
2.5	3.1.4	Uncertainties in the Source Release Assessment
3.2		sure Assessment
	3.2.1	Exposure Setting
	3.2.2	Selection of Exposure Pathways 3-40

	3.2.3	Exposure-Point Concentrations	3-43
	3.2.4	Estimating Potential Dose Rates	3-56
	3.2.5	Uncertainty and Variability	3-75
	3.2.6	Summary	3-77
3.3	Humai	n Health and Ecological Hazards Summary	3-80
	3.3.1	Carcinogenicity	
	3.3.2	Chronic Effects (Other than Carcinogenicity)	
	3.3.3	Ecological Hazard Summary	
	3.3.4	Summary	
3.4	Risk C	Characterization	
	3.4.1	Summary of Exposure Assessment	3-104
	3.4.2	Summary of Human Health Hazards Assessment	
	3.4.3	Summary of Ecological Hazards Assessment	
	3.4.4	Methods Used to Calculate Human Health Risks	
	3.4.5	Results of Calculating Human Health Risk Indicators	
	3.4.6	Evaluation of Lead Risks from Tin-Lead Solder Used in the HASL	
		Process	3-125
	3.4.7	Results of Calculating Ecological (Aquatic) Risk Indicators	
	3.4.8	Uncertainties	
	3.4.9	Conclusions	
3.5	Proces	ss Safety Assessment	
	3.5.1	Chemical Safety Concerns	
	3.5.2	Hot Air Solder Leveling (HASL) Process Safety Concerns	
	3.5.3	Process Safety Concerns	
Refe	rences		3-151
Char	oter 4		
_		ess	4-1
4.1	-	mance Demonstration Results	
	4.1.1	Background	
	4.1.2	Performance Demonstration Methodology	
	4.1.3		
	4.1.4	Environmental Testing Methodology	
	4.1.5	Analysis of the Test Results	
	4.1.6	Overview of Test Results	
	4.1.7	HCLV Circuitry Performance Results	
	4.1.8	HVLC Circuitry Performance Results	
	4.1.9	High Speed Digital Circuitry Performance Results	
		High Frequency Low Pass Filter Circuitry Performance Results	
		High Frequency Transmission Line Coupler Circuitry Performance	
		Results	4-27
	4.1.12	Leakage Measurements Performance Results	
		Stranded Wires	
		Failure Analysis	
		Summary and Conclusions	
		Boxplot Displays	

4.2	Cost A	Analysis	. 4-55
	4.2.1	Overview of the Cost Methodology	. 4-56
	4.2.2	Cost Categories and Discussion of Unquantifiable Costs	. 4-57
	4.2.3	Simulation Modeling of Surface Finishing Processes	. 4-62
	4.2.4	Activity-Based Costing	. 4-68
	4.2.5	Cost Formulation Details and Sample Calculations	. 4-71
	4.2.6	Results	
	4.2.7	Conclusions	. 4-86
4.3	Regula	atory Assessment	. 4-88
	4.3.1	Clean Water Act	. 4-88
	4.3.2	Clean Air Act	. 4-93
	4.3.3	Resource Conservation and Recovery Act	. 4-95
	4.3.4	Comprehensive Environmental Response, Compensation and	
		Liability Act	. 4-97
	4.3.5	Superfund Amendments and Reauthorization Act and Emergency	
		Planning and Community Right-To-Know Act	. 4-98
	4.3.6	Toxic Substances Control Act	
	4.3.7	Summary of Regulations for Surface Finishing Technologies	
Refere	ences		
Chapt	ter 5		
_			5-1
5.1	Resour	rce Conservation	5-1
	5.1.1	Consumption of Natural Resources	5-2
	5.1.2	Consumption of Other Resources	5-8
	5.1.3	Summary and Conclusions	. 5-10
5.2	Energy	y Impacts	. 5-12
	5.2.1	Energy Consumption During Surface Finishing Process Operation	. 5-12
	5.2.2	Energy Consumption Environmental Impacts	. 5-18
	5.2.3	Energy Consumption in Other Life-Cycle Stages	
	5.2.4	Summary and Conclusions	
Refere	ences	·	
Chapt	ter 6		
_		vironmental Improvements Opportunities	6-1
6.1		ion Prevention	
	6.1.1	Management and Personnel Practices	
	6.1.2	Materials Management and Inventory Control	
	6.1.3	Material Selection	
	6.1.4	Process Improvements	
6.2		le, Recovery, and Control Technologies Assessment	
J. <u> </u>	6.2.1	Recycle and Resource Recovery Opportunities	
	6.2.2	Control Technologies	
Refere	ences		

Chapt	er 7		
Choos	ing Am	ong Surface Finishing Technologies	. 7-1
7.1	Risk,	Competitiveness, and Conservation Data Summary	. 7-2
	7.1.1	Risk Summary	. 7-2
	7.1.2	Competitiveness Summary	. 7-8
	7.1.3	Resource Conservation Summary	7-14
7.2	Social	Benefits/Costs Assessment	7-16
	7.2.1	Introduction to Social Benefits/Costs Assessment	7-16
	7.2.2	Benefits/Costs Methodology and Data Availability	7-18
	7.2.3	Private and External Benefits and Costs Associated with Choice of	
		Surface Finishing Alternative	7-19
	7.2.4	Summary of Benefits and Costs	7-28
7.3	Techn	ology Summary Profiles	7-30
	7.3.1	HASL Technology	7-30
	7.3.2	Nickel/Gold Technology	7-35
	7.3.3	Nickel/Palladium/Gold Technology	7-39
	7.3.4	OSP Technology	7-44
	7.3.5	Immersion Silver Technology	7-47
	7.3.6	Immersion Tin Technology	7-51
Refere	nces		7-56

List of Tables

Table 1-1.	Surface Finishing Technologies Submitted by Chemical Suppliers 1-11
Table 1-2.	Responses to the PWB Workplace Practices Questionnaire 1-13
Table 2-1.	Use Cluster Chemicals and Associated Surface Finishing Processes 2-18
Table 3-1.	Water Usage of Surface Finishing Technologies From Questionnaire 3-7
Table 3-2.	Reported Use of Chemical Flushing as a Tank Cleaning Method 3-8
Table 3-3.	Average Bath Dimensions and Temperatures for All Processes
Table 3-4.	Spent Bath Treatment and Disposal Methods
Table 3-5.	RCRA Wastes and Container Types for Surface Finishing Technologies 3-16
Table 3-6.	Workplace Activities and Associated Potential Exposure Pathways 3-40
Table 3-7.	Potential Population Exposure Pathways
Table 3-8.	Results of Workplace Air Modeling 3-47
Table 3-9.	Results of Ambient Air Modeling
Table 3-10.	Estimated Releases to Surface Water Following Treatment
Table 3-11.	Parameter Values for Workplace Inhalation Exposures
Table 3-12.	General Parameter Values for Workplace Dermal Exposures
Table 3-13.	Parameter Values for Workplace Dermal Exposures for Line Operators
	on Non-Conveyorized Lines
Table 3-14.	Parameter Values for Workplace Dermal Exposure for Line Operators
	on Conveyorized Lines
Table 3-15.	Parameter Values for Workplace Dermal Exposure for a Laboratory
	Technician on Either Conveyorized or Non-Conveyorized Lines
Table 3-16.	Estimated Average Daily Dose for Workplace Exposure From Inhalation
	and Dermal Contact
Table 3-17.	Estimated Concentration of Lead in Adult and Fetal Blood from Incidental
14010 0 171	Ingestion of Lead in Tin/Lead Solder
Table 3-18.	Parameter Values for Estimating Nearby Residential Inhalation Exposure 3-74
Table 3-19.	Estimated Average Daily Dose for General Population Inhalation
14010 5 15.	Exposure
Table 3-20.	Children's Blood-Lead Results from the IEUBK Model at Various Lead
14010 5 20.	Air Concentrations
Table 3-21.	Available Carcinogenicity Information
Table 3-22.	Summary of RfC and RfD Information used in Risk Characterization for
14010 5 22.	Non-Proprietary Ingredients
Table 3-23.	NOAEL/LOAEL Values Used in Risk Characterization for
14010 5 25.	Non-Proprietary Ingredients
Table 3-24.	Developmental Toxicity Values Used in Risk Characterization for
14010 5 2 1.	Non-Proprietary Ingredients
Table 3-25.	Summary of Health Effects Information
Table 3-26.	Overview of Available Toxicity Data
Table 3-20.	Estimated (Lowest) Aquatic Toxicity Values and Concern Concentrations
14010 3 21.	for PWB Surface Finishing Chemicals, Based on Measured Test Data or
	SAR Analysis
Table 3-28.	Environmental Hazard Ranking of PWB Finishing Chemicals
1 4010 5 20.	Divisorium ruzure rumanig or i vib i inisimig chemicais 3-100

Table 3-29.	Gastrointestinal (GI) Absorption Factors	3-112
Table 3-30.	Summary of Human Health Risks From Occupational Inhalation	
	Exposure for Selected Chemicals	3-116
Table 3-31.	Summary of Human Health Risks Results From Occupational Dermal	
	Exposure for Selected Chemicals	3-118
Table 3-32.	Summary of Potential Human Health Effects for Chemicals of Concern 3	3-121
Table 3-33.	Data Gaps for Chronic Non-Cancer Health Effects for Workers 3	
Table 3-34.	Risk Evaluation Summary for Lead 3	
Table 3-35.	Summary of Aquatic Risk Indicators for Non-Metal Chemicals	
	of Concern 3	3-129
Table 3-36.	Summary of Aquatic Risk Indicators for Metals Assuming No On-Site	
	Treatment	3-130
Table 3-37.	Overall Comparison of Potential Human Health and Ecological Risks	
	for the Non-Conveyorized HASL and Alternative Processes	3-136
Table 3-38.	Flammable, Combustible, Explosive, and Fire Hazard Possibilities for	
	Surface Finishing Processes	3-139
Table 3-39.	Corrosive, Oxidizer, Reactive, Unstable, and Sudden Release of Pressure	, 10,
10010 0 05.	Possibilities for Surface Finishing Processes	3-141
Table 3-40.	Sensitizer, Acute and Chronic Health Hazards, and Irreversible	, , , , ,
14010 5 10.	Eye Damage Possibilities for Surface Finishing Processes	3-143
Table 4-1.	Electrical Responses for the Test PWA and Acceptance Criteria	
Table 4-2.	Distribution of the Number of LRSTF PWAs by Surface Finish,	
14010 1 2.	Site, and Flux	4-7
Table 4-3.	Listing of 23 Site/Flux Combinations Used in the Multiple Comparisons	,
14010 1 5.	Analyses	4-11
Table 4-4.	Number of Anomalies Observed at Each Test Time	
Table 4-5.	Percentage of Circuits Meeting Acceptance Criteria at Each Test Time	
Table 4-6.	Comparison of CCAMTF Pre-Test Ranges with DfE Pre-Test	
14010 1 0.	Measurements	4-15
Table 4-7.	Frequency Distribution of Post 85/85 Anomalies per PWA by	1 13
Tuble 17.	Surface Finish	4-16
Table 4-8.	Frequency Distribution of Post-Thermal Shock Anomalies per PWA by	1 10
Table 4 0.	Surface Finish	4-17
Table 4-9.	Frequency Distribution of Post-Mechanical Shock Anomalies per PWA by	1 1 /
Table 4 7.	Surface Finish	4-18
Table 4-10.	P-Values for HCLV Test Results	
Table 4-11.	Number of HCLV PTH Anomalies at Post-Mechanical Shock by	T -1)
14010 + 11.	Surface Finish	4-20
Table 4-12.	P-Values for HVLC Test Results	
Table 4-13.	P-Values for HSD Test Results	
Table 4-14.	P-Values for HF LPF Test Results	
Table 4-14.	Frequency Distribution of HF LPF Anomalies at Post-Mechanical Shock	∠ 3
1 auic 4-1J.	per PWA	1_25
Table 4-16.	Comparison of the Observed and Expected Number of Anomalies for	+ -23
1 autc 4-10.	the HF LPF PTH 50MHz Circuit by Surface Finish	1 26
	THE THE LET TELL THE SOLVENIZ CHECKED BY SUFFICE PHILISH	 -∠0

Table 4-17.	Comparison of the Observed and Expected Number of Anomalies Under th	e
	Hypothesis of Independence of Surface Finishes	. 4-26
Table 4-18.	P-Values for HF TLC Test Results	. 4-28
Table 4-19.	P-Values for Leakage Test Results	. 4-30
Table 4-20.	P-Values for Stranded Wire Test Results	. 4-32
Table 4-21.	Identification of Assemblies Selected for Ion Chromatography Analysis	. 4-35
Table 4-22.	Ion Chromatography Anion (-) Data (HASL)	. 4-36
Table 4-23.	Ion Chromatography Anion (-) Data (Immersion Tin)	. 4-36
Table 4-24.	Ion Chromatography Anion (-) Data (Immersion Silver)	. 4-37
Table 4-25.	Ion Chromatography Anion (-) Data (Nickel/Gold)	. 4-37
Table 4-26.	Ion Chromatography Anion (-) Data (OSP)	. 4-37
Table 4-27.	Ion Chromatography Anion (*) Data (Nickel/Palladium/Gold)	. 4-38
Table 4-28.	Acceptance Levels for Weak Organic Acids	. 4-39
Table 4-29.	Frequency of Anomalies by Individual Circuit Over Test Times	. 4-41
Table 4-30.	Surface Finishing Processes Evaluated in the Cost Analysis	. 4-55
Table 4-31.	Cost Component Categories	. 4-58
Table 4-32.	Number of Filter Replacements by Surface Finishing Process	. 4-62
Table 4-33.	Bath Volumes Used for Conveyorized Processes	. 4-64
Table 4-34.	Time-Related Input Values for Non-Conveyorized Processes	. 4-65
Table 4-35.	Time-Related Input Values for Conveyorized Processes	. 4-65
Table 4-36.	Bath Replacement Criteria for Nickel/Gold Processes	. 4-66
Table 4-37.	Frequency and Duration of Bath Replacements for Non-Conveyorized	
	Nickel/Gold Process	. 4-67
Table 4-38.	Production Time and Down Time for the Surface Finishing Processes to	
	Produce 260,000 ssf of PWB	. 4-68
Table 4-39.	BOA for Transportation of Chemicals to the Surface Finishing	
	Process Line	. 4-70
Table 4-40.	Costs of Critical Tasks	. 4-71
Table 4-41.	Materials Cost for the Non-Conveyorized Nickel/Gold Process	. 4-76
Table 4-42.	Chemical Cost per Bath Replacement for One Product Line of the	
	Non-Conveyorized Nickel/Gold Process	. 4-76
Table 4-43.	Tiered Cost Scale for Monthly Wastewater Discharges to a POTW	. 4-79
Table 4-44.	Summary of Costs for the Non-Conveyorized Nickel/Gold Process	
Table 4-45.	Total Cost of Surface Finishing Technologies	. 4-84
Table 4-46.	Surface Finishing Alternative Unit Costs for Producing 260,000 ssf	
	of PWB	. 4-86
Table 4-47.	CWA Regulations That May Apply to Chemicals in the Surface	
	Finishing Process	. 4-89
Table 4-48.	Printed Circuit Board Facilities Discharging Less than 38,000 Liters per	
	Day PSES Limitations (mg/L)	. 4-91
Table 4-49.	Printed Circuit Board Facilities Discharging 38,000 Liters per Day or	
	More PSES Limitations (mg/L)	. 4-91
Table 4-50.	PSNS for Metal Finishing Facilities	
Table 4-51.	Amenable Cyanide Limitation Upon Agreement	
Table 4-52.	PSES for All Plants Except Job Shops and Independent PWB	
	Manufacturers	. 4-92

Table 4-53.	CAA Regulations That May Apply to Chemicals in the Surface
	Finishing Process
Table 4-54.	CERCLA RQs That May Apply to Chemicals in the Surface Finishing
	Process
Table 4-55.	SARA and EPCRA Regulations That May Apply to Chemicals in the
	Surface Finishing Process 4-99
Table 4-56.	TSCA Regulations and Lists That May Apply to Chemicals Used
	in Surface Finishing Processes 4-100
Table 4-57.	Summary of Regulations that May Apply to Chemicals Used in
	Hot Air Solder Leveling (HASL) Technology 4-102
Table 4-58.	Summary of Regulations that May Apply to Chemicals Used in
	Nickel/Gold Technology 4-103
Table 4-59.	Summary of Regulations that May Apply to Chemicals Used in
	Nickel/Palladium/Gold Technology
Table 4-60.	Summary of Regulations that May Apply to Chemicals Used in
	OSP Technology 4-105
Table 4-61.	Summary of Regulations that May Apply to Chemicals Used in
	Immersion Silver Technology
Table 4-62.	Summary of Regulations that May Apply to Chemicals Used in
	Immersion Tin Technology
Table 5-1.	Effects of Surface Finishing Technology on Resource Consumption 5-2
Table 5-2.	Normalized Water Flow Rates of Various Water Rinse Types 5-4
Table 5-3.	Rinse Water Consumption Rates and Total Water Consumed by
	Surface Finishing technologies 5-5
Table 5-4.	Metal Deposition Rates and Total Metal Consumed by Surface
	Finishing Technologies
Table 5-5.	Energy-Consuming Equipment Used in Surface Finishing Process Lines 5-13
Table 5-6.	Number of Surface Finishing Process Stages that Consume Energy by
	Function of Equipment
Table 5-7.	Energy Consumption Rates for Surface Finishing Equipment 5-15
Table 5-8.	Hourly Energy Consumption Rates for Surface Finishing Technologies 5-16
Table 5-9.	Energy Consumption Rate per ssf of PWB Produced for Surface
	Finishing Technologies
Table 5-10.	Effects of Automation on Energy Consumption for Surface Finishing
	Technologies
Table 5-11.	Pollution Resulting From the Generation of Energy Consumed by
	Surface Finishing Technologies 5-20
Table 5-12.	Pollutant Environmental and Human Health Concerns 5-21
Table 6-1.	Management and Personnel Practices Promoting Pollution Prevention 6-4
Table 6-2.	Materials Management and Inventory Control Pollution Prevention
	Practices
Table 6-3.	Pollution Prevention Practices to Reduce Bath Contaminants 6-9
Table 6-4.	Methods for Reducing Chemical Bath Drag-Out 6-11
Table 6-5.	Bath Maintenance Improvement Methods to Extend Bath Life 6-12
Table 6-6.	Typical Value of Reclaimed Metals (1999) and Recovery Methods 6-26
Table 6-7.	Applicability of Recovery/Reclamation Technologies by Bath Type 6-28

Table 6-8.	Treatment Chemicals Used to Remove Metals From Chelated Wastewater 6-34
Table 6-9.	Treatment Profile of PWB Surface Finishing Process Baths 6-36
Table 7-1.	Surface Finishing Processes Evaluated in the CTSA
Table 7-2.	Surface Finishing Chemicals of Concern for Potential Occupational
	Inhalation Risk 7-4
Table 7-3.	Chemicals of Concern for Potential Dermal Risks
Table 7-4.	Aquatic Risk of Non-Metal Chemicals of Concern
Table 7-5.	Chemical Hazards 7-8
Table 7-6.	Cost of Surface Finishing Technologies
Table 7-7.	Regulatory Status of Surface Finishing Technologies
Table 7-8.	Energy and Water Consumption Rates of Surface Finishing Alternatives 7-14
Table 7-9.	Glossary of Benefits/Costs Analysis Terms
Table 7-10.	Overview of Potential Private and External Benefits or Costs
Table 7-11.	Overall Cost Comparison, Based on Manufacturing 260,000 ssf 7-21
Table 7-12.	Summary of Occupational Hazards, Exposures, and Risks of
	Potential Concern
Table 7-13.	Potential Health Effects Associated with Surface Finishing Chemicals of
	Concern 7-23
Table 7-14.	Number of Chemicals with Estimated Surface Water Concentration
	Above Concern Concentration
Table 7-15.	Energy and Water Consumption of Surface Finishing Technologies 7-27
Table 7-16.	Examples of Private Costs and Benefits Not Quantified
Table 7-17.	Summary of Human Health and Environmental Risk Concerns for the
	HASL Technology 7-31
Table 7-18.	Number of HASL Chemicals Subject to Applicable Federal Regulations 7-34
Table 7-19.	Summary of Human Health and Environmental Risk Concerns for
	the Nickel/Gold Technology 7-35
Table 7-20.	Number of Nickel/Gold Chemicals Subject to Applicable Federal
	Regulations
Table 7-21.	Summary of Human Health and Environmental Risk Concerns for the
	Nickel/Palladium/Gold Technology 7-40
Table 7-22.	Number of Nickel/Palladium/Gold Chemicals Subject to Applicable Federal
	Regulations
Table 7-23.	Summary of Human Health and Environmental Risk Concerns for the OSP
	Technology
Table 7-24.	Number of OSP Chemicals Subject to Applicable Federal Regulations 7-47
Table 7-25.	Summary of Human Health and Environmental Risk Concerns for the
	Immersion Silver Technology
Table 7-26.	Number of Immersion Silver Chemicals Subject to Applicable Federal
	Regulations
Table 7-27.	Summary of Human Health and Environmental Risk Concerns for the
	Immersion Tin Technology
Table 7-28.	Number of Immersion Tin Chemicals Subject to Applicable Federal
	Regulations

List of Figures

Figure 1-1.	PWBs Produced for World Market in 1998 (IPC)	. 1-6
Figure 1-2.	Number of PWBs Produced by U.S. Manufacturers in 1998 (IPC)	. 1-7
Figure 2-1.	Typical Process Steps for Surface Finishing Technologies	
Figure 2-2.	HASL Process Flow Diagram	. 2-6
Figure 2-3.	Nickel/Gold Process Flow Diagram	. 2-8
Figure 2-4.	Nickel/Palladium/Gold Process Flow Diagram	2-11
Figure 2-5.	OSP Process Flow Diagram	2-13
Figure 2-6.	Immersion Silver Process Flow Diagram	2-15
Figure 2-7.	Immersion Tin Process Flow Diagram	2-16
Figure 3-1.	Schematic of Overall Material Balance for Surface Finishing Technologes	. 3-4
Figure 3-2	Wastewater Treatment Process Flow Diagram	. 3-5
Figure 3-3.	Generic HASL Process Steps and Typical Bath Sequence	
Figure 3-4.	Generic Nickel/Gold Process Steps and Typical Bath Sequence	
Figure 3-5.	Generic Nickel/Palladium/Gold Process Steps and Typical Bath Sequence	3-24
Figure 3-6.	Generic OSP Process Steps and Typical Bath Sequence	3-27
Figure 3-7.	Generic Immersion Silver Process Steps and Typical Bath Sequence	
Figure 3-8.	Generic Immersion Tin Process Steps and Typical Bath Sequence	
Figure 3-9.	Relationship Between Intake Rate and Blood-Lead Level for Both Adult and Fetus	
Figure 4 1		3-13
Figure 4-1.	Boxplot Displays for HCLV PTH Measurements (volts) at Pre-Test	4-43
Eigyma 4.2	by Surface Finish	4-43
Figure 4-2.	Boxplot Displays for HCLV PTH Post 85/85 - Pre-Test Measurements	4-43
Eigung 4.2	(volts) by Surface Finish	4-43
Figure 4-3.	Boxplot Displays for HCLV PTH Post TS - Pre-Test Measurements	4-44
Eigyma 4 4	(volts) by Surface Finish	4-44
Figure 4-4.	Boxplot Displays for HCLV PTH Post MS - Pre-Test Measurements	4-44
Eigyma 4.5	(volts) by Surface Finish	4-44
Figure 4-5.	Boxplot Displays for HCLV SMT Measurements (volts) by Surface Finish	1 15
Eigyma 1 6		4-45
Figure 4-6.	Boxplot Displays for HCLV PTH Post 85/85 - Pre-Test Measurements	4-45
Eigyma 4.7	(volts) by Surface Finish	4-43
Figure 4-7.	(volts) by Surface Finish	1 16
E: 1 0		4-40
Figure 4-8.	Boxplot Displays for HCLV PTH Post MS - Pre-Test Measurements	1 16
F: 1.0	(volts) by Surface Finish	4-40
Figure 4-9.	Boxplot Displays for HF PTH 50MHz Measurements (volts) by	4 47
E 4 10	Surface Finish	4-4/
Figure 4-10.	Boxplot Displays for HF PTH 50MHz Post MS - Pre-Test Measurements	1 17
F' 4 1 1	(volts) by Surface Finish	4-47
Figure 4-11.	Boxplot Displays for HF PTH f(-3dB) Post MS - Pre-Test Measurements	4 40
E' 4.10	(MHz) by Surface Finish	4-48
Figure 4-12.	Boxplot Displays for HF PTH f(-40dB) Post MS - Pre-Test Measurements	4 40
	(MHz) by Surface Finish	4-48

Figure 4-13.	Boxplot Displays for HF SMT 50MHz Post Ms - Pre-Test Measurements (dB) by Surface Finish	4-49
Figure 4-14.	Boxplot Displays for HF SMT f(-3dB) Post MS - Pre-Test Measurements	1 17
riguie i i i.		4-49
Figure 4-15.	Boxplot Displays for HF PTH f(-40dB) Post MS - Pre-Test Measurements	
C		4-50
Figure 4-16.	Boxplot Displays for HF TLC 50MHz Post MS - Pre-Test Measurements	
C		4-50
Figure 4-17.	Boxplot Displays for HF TLC 500MHz Post MS - Pre-Test Measurements	
C		4-51
Figure 4-18.	Boxplot Displays for HF TLC RNR Post MS - Pre-Test Measurements	
_	(dB) by Surface Finish	4-51
Figure 4-19.	Boxplot Displays for 10-Mil Pad Measurements (log ₁₀ ohms) at Pre-Test	
		4-52
Figure 4-20.	Boxplot Displays for 10-Mil Pad 85/85 Pre-Test Measurements (log ₁₀ ohms)	
	by Surface Finish	4-52
Figure 4-21.	Boxplot Displays for PGA-A Measurements (log ₁₀ ohms) at Pre-Test by	
	Surface Finish	4-53
Figure 4-22.	Boxplot Displays for PGA-B Measurements (log ₁₀ ohms) at Pre-Test by	
	Surface Finish	4-53
Figure 4-23.	Boxplot Displays for the Gull Wing Measurements (log ₁₀ ohms) at Pre-Test	
	by Surface Finish	4-54
Figure 4-24.	Hybrid Cost Analysis Framework	4-56
Figure 5-1.	Water Consumption Rates of Surface Finishing Technologies	5-5
Figure 6-1.	Solder Reclaim System Diagram	6-21
Figure 6-2.	Flow Diagram of Combination Ion Exchange and Electrowinning	
	Recovery System for Metal Recovery	6-24
Figure 6-3.	Reverse Osmosis Water Reuse System	6-25
Figure 6-4.	Typical PWB Waste Treatment System	6-32
Figure 7-1.	Production Costs and Resource Consumption of Conveyorized	
		7-33
Figure 7-2.	Production Costs and Resource Consumption of the Nickel/Gold	
	Technology	7-38
Figure 7-3.	Production Costs and Resource Consumption of Nickel/Palladium/Gold	
		7-43
Figure 7-4.	Production Costs and Resource Consumption of OSP Technology	7-46
Figure 7-5.	Production Costs and Resource Consumption of Immersion Silver	
	<i>U</i>	7-49
Figure 7-6.	Production Costs and Resource Consumption of Immersion Tin	
	Technology	7-54